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ABSTRACT

This study describes the rationale and activities developed and tested by a project in Israel entitled Biology Critical Thinking (BCT). The BCT project aims at developing a pool of activities that can be incorporated within the regular course of study without investing too much extra time. The purposes of the study are: (1) to present the rationale of the BCT project; (2) to describe an example of a BCT activity, and the responses to it in the classroom; and (3) to report the results of a pilot study that examined the feasibility of implementing some BCT activities. This study may be regarded as a small step in the direction of developing reasoning skills through activities which can be readily incorporated into the regular school curriculum by the majority of classroom teachers. (23 references) (KR)

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INCORPORATING CRITICAL THINKING INTO A REGULAR HIGHSCHOOL BIOLOGY CURRICULUM

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Introduction

Critical thinking has been defined as "suspension of judgement" (Mcpeck, 1981), as "the correct assessment of judgement" (Ennis, 1962), or as "reasonable reflective thinking focused on deciding what to believe or do" (Ennis, 1989). The development of critical thinking has been regarded since ancient times as one of the major aims of education (Resnick, 1987). Yet, studies have revealed time and again that quite often students fail in tasks which require critical thinking (e.g. Jungwirth, 1985; Jungwirth & Dreyfus, 1990). Moreover, students who had studied the "new" inquiry oriented science curricula of the 1960's performed as poorly as their "traditional" counterparts (Shulman & Tamir, 1973). It appears that critical thinking does not develop in passing, but rather explicit and deliberate efforts are needed in order to develop it.

Indeed, the results of several studies indicate that learning experiences explicitly designed to develop reasoning skills achieve their goal to various degrees (Kaplan, 1967; Wheatly, 1975; Reif & St. John, 1979; Pappalis et al, 1980; Friedler & Tamir, 1986).

Educators have been and are still debating on the best approach for enhancing the development of reasoning skills. Two major unresolved issues in this debate are: a) To what extent reasoning skills are general, content-free or, rather, subject matter and concept specific abilities; and, related to it, b) The extent to which and the circumstances under which transfer of critical thinking takes place. The answers to these questions have significant implications for instruction. The major dilemma is whether we should design special courses for teaching thinking skills as implied by the "general" approach or, instead, infuse the development of thinking within regular disciplinary courses - the "infusion" approach (Mcpeck, 1981; Resnick, 1987; Ennis, 1989).

Perkins & Salomon (1989) have reviewed the debates and disagreements along with pertinent research and concluded that the truth lies

somewhere in the middle. Critical thinking like other reasoning skills has at the same time both general and content dependent attributes. Since the regular school curriculum is already over crowded, they predict that "wider scale efforts to join subject matter instruction and teaching of thinking will be one of the exciting stories of the next decade of research and educational innovations" (p. 24).

Several examples of projects that were designed according to the "general" approach are Philosophy for Children (Lipman, 1985), Cort (De Bono, 1985) & Odyssey (Dominguez & al., 1986). Similarly, various projects have been designed according to the "infusion" approach. One of the disciplines in which such projects have been uttered is biology (e.g. Jungwirth, Dreyfus & Amir, 1986; Statkievicz & Allen, 1983; Moll & Allen, 1982; Novak & Dettloff, 1989). However, routine use of specially designed activities has yet to be realized.

The present study describes the rationale and activities developed and trialled by a project entitled Biology Critical Thinking (BCT). The BCT project aims at developing a pool of activities which can be incorporated within the regular course of study without investing too much extra time (see Meyers, 1987).

Purpose of Study

The purposes of study are:

1. To present the rationale of the BCT project.
2. To describe an example of a BCT activity, and the responses to it in the classroom.
3. To report the results of a pilot study that examined the feasibility of implementing some BCT activities.

Design and Procedures

Guidelines

The following guidelines have been adopted by the BCT project:

1. The critical thinking activities will constitute an integral component of the regular curriculum. No attempt is made to develop a new biology curriculum.
2. In order to enhance transfer the same skill should be applied in many occasions and in a variety of contexts.
3. The activity will include metacognitive discussions of the particular reasoning skills and how they were used.
4. The time devoted to the activity should be reasonably short, so that other instructional goals will not be deprived.

Skills

As a first step the following ten skills (abilities) were selected as goals of the BCT:

1. Distinguish between findings of an experiment and conclusions made on the basis of the findings.
2. Draw valid conclusions from given data.
3. Identify and evaluate control.
4. Design adequate controls.
5. Identify explicit and hidden assumptions.
6. Determine logical fallacies such as jumping to conclusions or overgeneralizations.
7. Tautology.
8. Isolating variables.
9. Testing hypotheses (hypothetic reasoning expressed as "if...then...").
10. Critical appraisal of advertisments.

Examination of the above list shows a partial overlap with "scientific inquiry skills" (Schwab, 1962; Shulman & Tamir, 1973; Tamir & Lunetta, 1978). This is not surprising. On the one hand, according to the "infusion" approach critical thinking in each knowledge domain is specified by the knowledge structure of the pertinent discipline. Different subjects have different types of "good reasons" and of evidence: What counts as a "good reason" in Law, might not be

acceptable as "good reason" in mathematics or in science (Mcpeck, 1981). Scientific knowledge grows by the process of scientific inquiry. It follows that in order to be able to think criticaly about scientific knowledge, it is necessary to understand the processes by which scientific knowledge is created. No wonder that some of the critical thinking skills such as the first four in our list above will also be found in any list of scientific inquiry skills. At the same time, however, there is also an overlap between some general critical thinking skills, and certain scientific inquiry skills. The ability to draw valid conclusions for example (skill 2 on the above list), is one of the basic skills, to be found on every list of general critical thinking skills. Thus it appears that "scientific inquiry skills" are closely related to "scientific critical thinking skills". Nevertheless, the two are not identical and each deserves attention and treatment on its own rights.

Topics

The second step following the selection of skills was to identify topics included in the regular biology curriculum) which lend themselves to BCT activities (e.g. digestion). The final product of these two steps was a matrix of specific content areas matched with the ten skills listed above.

Activities

The third step involved the development of the activities indicated by the matrix. The time needed to complete these activities ranged between three minutes and two and a half periods.

Sample

The pilot study involved 77 9th grade students comprising 4 study groups. Two groups studied the regular biology program taught by an experienced teacher of high reputation. The remaining two groups were taught by the first author (who used to teach regularly in that school). Only the last two groups performed the BCT activities. Both groups used the same textbook. No extra time was allocated to the BCT groups. The BCT activities lasted 5 months.

Instruments

Three tests were used as follows:

1. Cornell Critical Thinking Test, Form Z (Ennis, 1961). This test was divided into two matched halves. One half was used as pretest and the other half was used as posttest. Our hypothesis was that on this posttest, there will be no significant difference between the two treatments, because: a. the skills assessed by Cornell Critical Thinking Test are different from those taught by the BCT project and, b. As yet it has not been shown that critical thinking skills transfer from one content domain to another.
2. The second test developed by the authors was designated as Critical Thinking Application Test (CAT). CAT evaluates performance in the 10 reasoning skills listed above. The tasks in this test are similar in structure to the BCT activities, but deal with different and unfamiliar content.
3. The third test consisted of eight multiple choice knowledge items, that were incorporated into the regular biology midterm examinations covering the topics represented in BCT.

Results and Discussion

The results are reported in two sections. First, a typical activity is described; and second, the results of a pilot evaluation study are reported.

The Vitamins Activity

While studying about vitamins, the students were introduced to an activity called "The importance of vitamin B". This activity was based on a description of an experiment, which investigated the influence of vitamin B1 on the heartbeat rate of mice: When one group of mice was given food with no vitamin B, their heartbeat decreased as a function of time. The conclusion presented was that vitamin B is necessary for maintaining the normal heartbeat rate. Obviously, this conclusion is not valid since the experiment lacks an adequate control. Part two of

this activity was designed to let the students become aware of the problems that might arise from lack of control. The students had not been familiar with the concept "control" prior to this activity. Following is the text for this activity:

> When the scientist told his friends about his conclusion one of the friends argued that this conclusion was not necessarily valid because the experiment had been conducted in January; hence, it was possible that the heartbeat rate decreased as a result of the cold and not because of the lack of vitamin B. Another friend argued that since 10 days after the onset of the experiment, the laboratory was sprayed with a strong poison against insects, the poison might have caused the decrease in the heartbeat rate of the mice.
>
> 1. What do you think: which of the scientists is right? - Explain.
> 2. Following are a number of suggestions for additional experiments. Please mark the experiment that the scientist has to perform in order to defend his conclusion against the claims of his friends. - Explain your choice.
>   a. Repeat the experiment in a warmer month (e.g. July).
>   b. Repeat the experiment, but make sure that the laboratory will not be sprayed during the experiment.
>   c. Repeat the experiment with two groups of mice: Group A will get regular nutririon, and Group B will get nutririon with no vitamin B.
>   d. Restore vitamin B to the diet of the mice and examine whether their heartbeat will return to normal.

To perform the task the students worked in small groups. The students got involved in hot debates, and a variety of answers were offered. After about 20 minutes, the teacher switched to a whole class discussion. Only towards the end of the lesson was the concept "control" invented and defined.

About 4 weeks later, during which the concept of control had not been mentioned, the class learned about digestion and discussed the role of

an enzyme found in the saliva. The students performed the following experiment: Each group received two plates with agar that contained starch. Wet bean seeds were cut into halves, and placed on the starch-agar in plate 1 for about 20 minutes, after which the seeds were removed. Now Lugol was poured in both plates. The results are presented in Figure 1.

Insert Figure 1 about here

Having examined plate 1 and describing what they saw, the students were asked to explain the results. Some of the students explained that the enzyme in the seeds digested the starch in the places where the seeds touched the agar, and this resulted in white spots following the treatment with Lugol. One of the students had then raised her hand and asked: "How do we know that this is indeed what happened? Perhaps whenever Lugol is added to starch-agar plate some white spots appear?" The teacher redirected the question to the rest of the class. Most of the students raised their hands eager to reply. Following are 3 examples of responses:

Liat: "This is exactly the same as with group 2 in the experiment with the vitamins and the mice".

Yfat: "But the reason we had plate 2 as a comparison was to answer such questions!"

David:"Because plate 2 was identical in all conditions to plate 1 except the examined factor which is the starch digesting enzyme".

It is worth noting that most students remembered the one experience they had had with "control" 4 weeks earlier, and were able to transfer their knowledge from one biological context (the experiment with the mice and vitamin B) to a different biological context (the experiment with the starch-digesting enzyme). However, analysis of the responses of individual students revealed that each student remembered things differently depending on his/her prior knowledge and cognitive level of development:

Liat is one of the weakest students in the class. The teacher was actually surprised at her answer since it was the first time that she volunteered to participate in a class discussion. As can be seen from her answer, she succeeded in seeing the similarity between the two experiments, but could not express any generalization. Yifat, an average student, was able to generalize and identify the aspect of "comparison" which is the essential element underlining the concept of control. Finally, David, one of the brightet students in the class, identified control with all its characteristics even though the term "control" was not mentioned. Interestingly, although most of the students showed varying degrees of understanding of the concept "control" none mentioned the term proper. Having realized that, the teacher asked: "How would you call the role of plate 2 in the described experiment?" None of the students remembered. Only when they were asked to open their notebooks and look at the summaries they had written 4 weeks earlier, they were reminded and began to use the term "control" in their replies.

This case illustrates the gap that might exist between knowing the name of a concept and understanding the meaning of that concept. It also relates to the question should the names of the reasoning skills be taught? Is it important for example to teach the terms "tautology", "isolation of variables", "logical fallacies" or "overgeneralization"? The case described in our study indicates that insisting on teaching such terms may not be necessary, since a reasoning pattern might be operational even though the formal term representing it is not known. Inventing the formal terms may be useful, but, at the same time, can impose a burden on the working memory. Further research is needed to provide guidance in this matter.

The Comparative Evaluation

Table I presents the results of the different tests. The experimental and comparison groups showed similar results in the pretest (mean score of 53.6 and 53.1 respectively), indicating that the two groups were equal before the treatment in their general critical thinking

abilities. Further support to the equality was provided by the practically identical results obtained in the second half of the Cornell Critical Thinking Test used as posttest (mean scores 49.5 & 49.8 respectively). These posttest results also indicate that the treatment had no effect on general critical thinking performance .

Insert Table 1 about here

On the other hand, the mean score in the CAT posttest was 59.9 and 31.4 for the experimental and the comparison groups respectively. This difference was found to be statistically significant ($t = 5.9$, $p < 0.001$). The scores of the experimental group were higher than those of the control group in each of the test's 14 items. Large differences between the two groups were found in items concerning the following: designing control in experiments, isolation of variables, tautology, and hypothetical reasoning.

It may be concluded that it is possible to complete both the regular curriculum and the BCT activities in the allocated time. No significant differences were found between the mean scores of the two groups in the knowledge test (89.1 and 74.8 in the experimental and comparison groups respectively). This result indicates that the time devoted to the BCT activities in the experimental group was not at the expense of acquiring knowledge. The data show a trend towards a higher knowledge gain in the BCT group in spite of the allocation of time to the BCT activities.

Based on the results of this small scale pilot study it may be concluded that infusion of BCT activities into the regular biology curriculum is feasible, does not require additional time, does not decrease knowledge gain and, at the same time, substantially enhances performance on subject matter specific critical thinking tasks. It is possible that if BCT activities will be used over a larger period of time and in a variety of contexts, some transfer may occur to reasoning beyobd the domain of biology.

Conclusions and Implications

The present study may be regarded as a small step in the direction of developing reasoning skills through activities which can be readily incorporated into the regular school curriculum by the majority of classroom teachers.

The results indicate that BCT is a feasible approach which yields positive outcomes. The advantages of this approach include the following: it does not distract the teacher from other educational goals; it does not require the investment of more time in a particular topic; and it does not demand special teaching skills on the part of the teacher. What is required is a conviction that it is important to enhance the development of reasoning skills, a repertoire of BCT activities matched to different topics and the inclusion of some tasks which involve critical thinking in the regular class tests. Further studies, on a larger scale, involving more BCT activities, more teachers, more students and larger periods of time, are needed before more detailed guidelines can be worked out and before more accurate expectations can be formulated.

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Table I

Mean Scores of the Experimental and the Comparison Groups in The 4 Tests

	Cornell pretest	Cornell posttest	CAT	Knowledge
Experimental group (n = 39)	53.6 S.D=11.4	49.5 S.D=13.7	59.9 S.D=20.5	89.1 S.D=6.9
Control group (n = 38)	53.1 S.D=14.5	49.8 S.D=16.1	31.4 S.D=18.1	74.8 S.D=28.1

Figure 1

Results of the Beans Experiment

When Lugol is added to starch, a purple color appears

Plate 1
There are white spots where
bean seeds were placed
for 20 minutes

Plate 2
The whole plate has
a purple color